Feedbacks:
Oceans and El Niño

EES 3310/5310

Global Climate Change

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Class #9: Monday, January 27 2020

Kombayashi-Ingersoll Limit

- Outgoing long-wave has to balance incoming sunlight
- no feedback, feedback, feedback + high CO_2
- Brighter sun $\longrightarrow$ hotter $\longrightarrow$ more water vapor
- Kombayashi-Ingersoll limit:
  - Sunlight below limit, there is a stable equilibrium with liquid water
  - Sunlight above limit, oceans boil dry

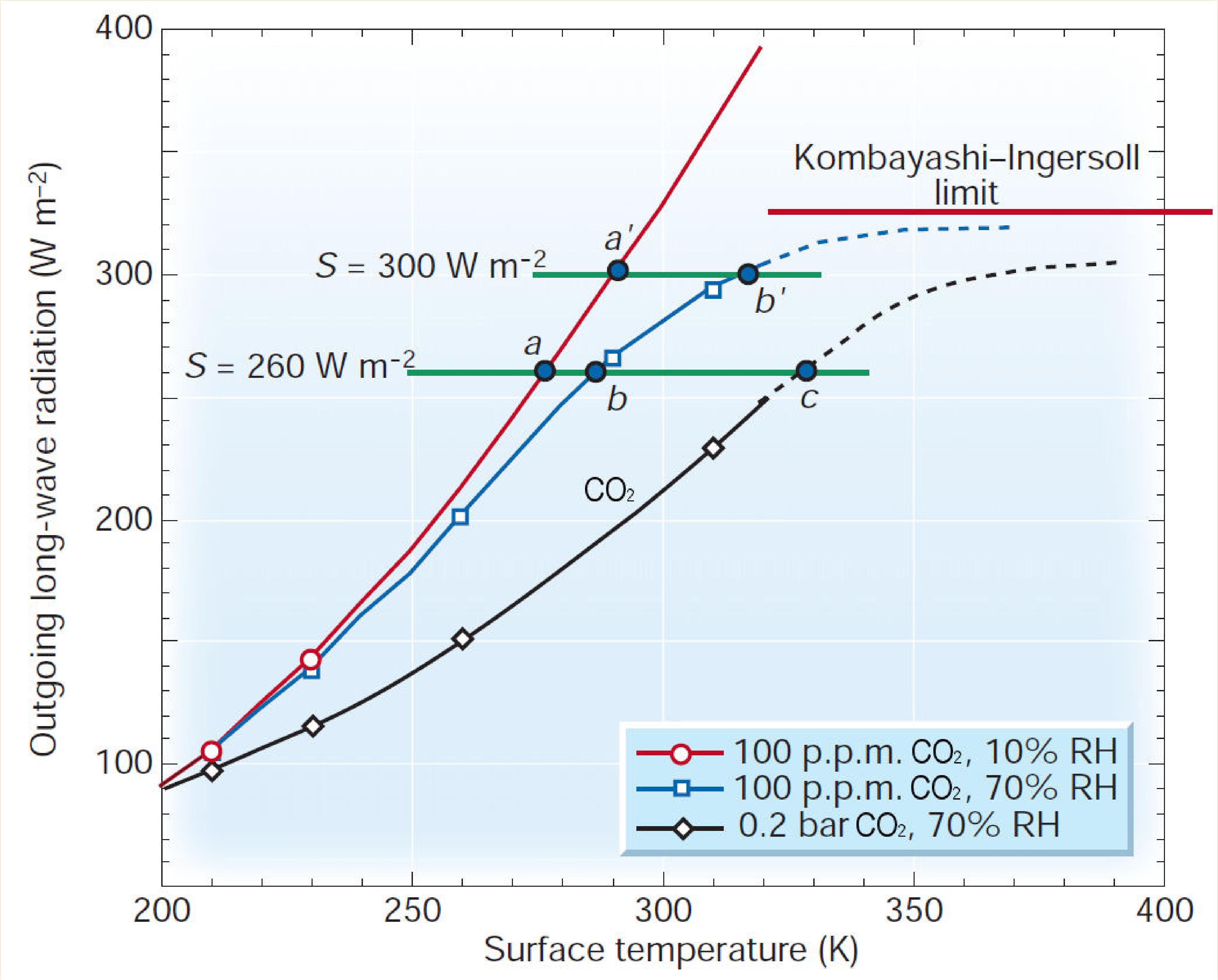


Image credit: R. Pierrehumbert, Nature **419**, 191 (2002) doi: 10.1038/nature01088

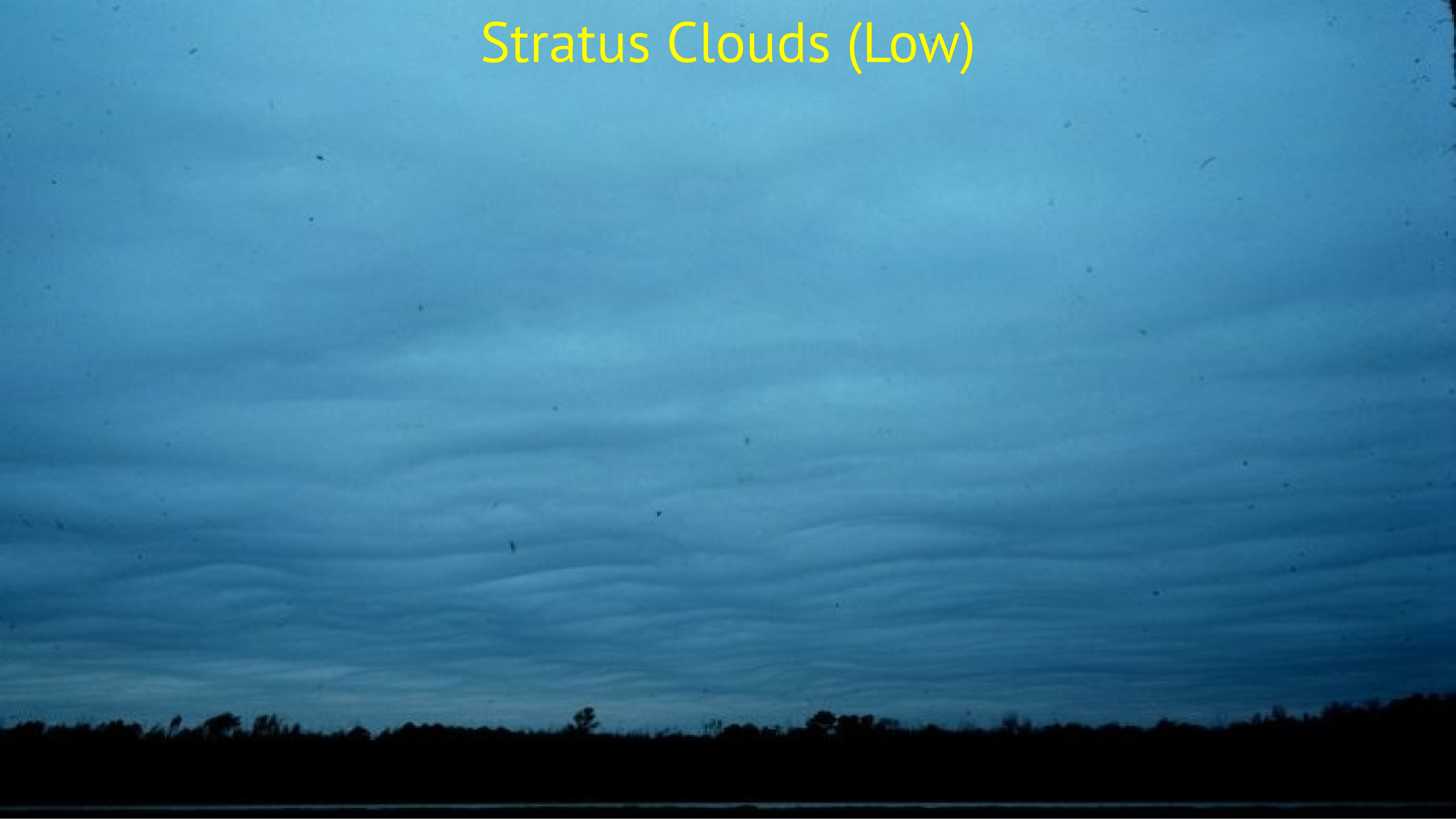
Cloud Feedbacks

Cloud Feedbacks

- What effect do clouds have on climate?
- What effects does climate have on clouds?
- Warmer $\rightarrow$ more clouds
- More clouds:
  - Higher albedo
    - (cools earth: negative feedback)
  - High emissivity: blocks longwave light
    - (warms earth: positive feedback)
- Which effect is bigger?

Cirrus Clouds (High)

Stratus Clouds (Low)



Cloud Feedbacks

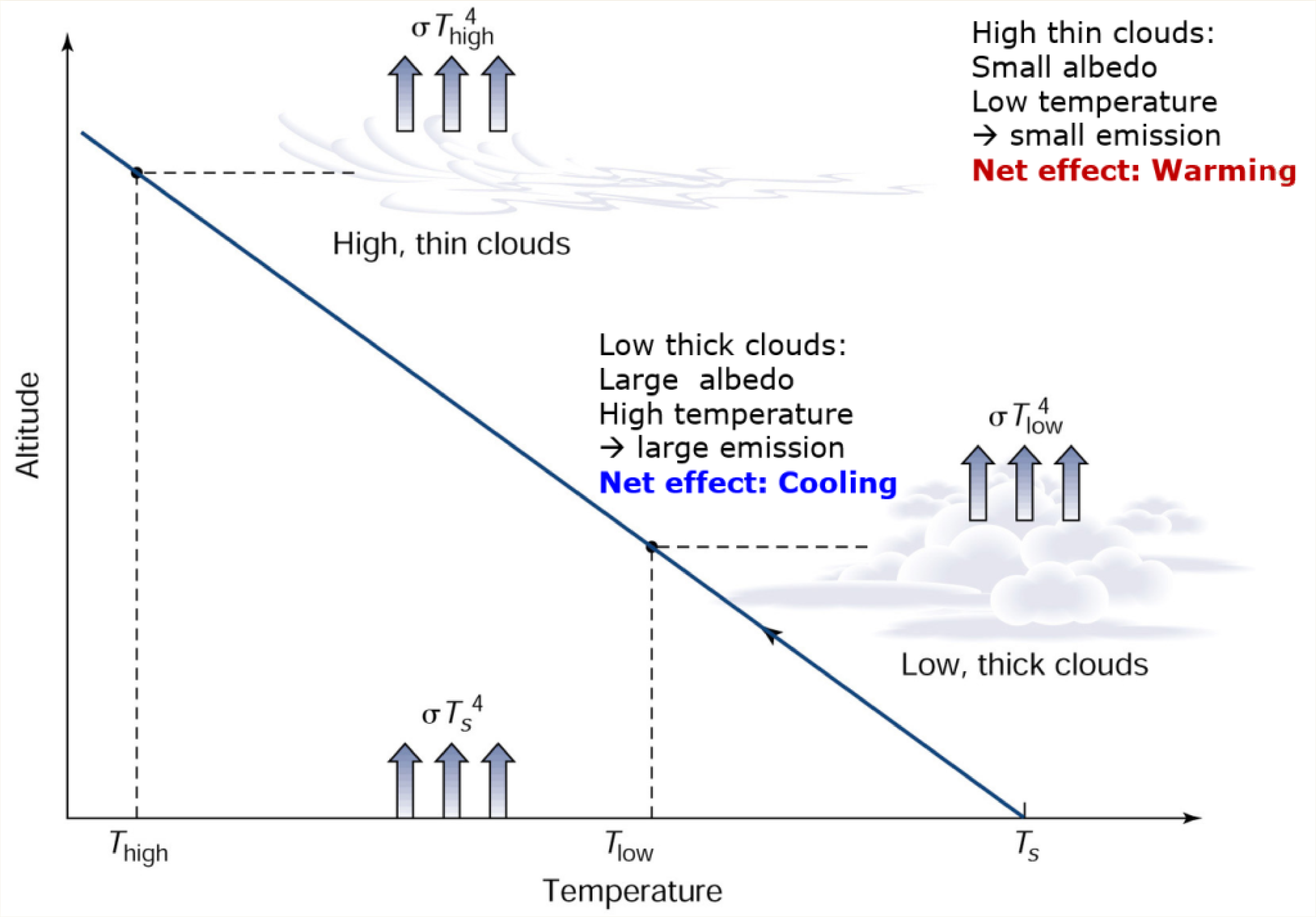


Image credit: L.R. Kump, J.F. Kasting, & R.G. Crane, *The Earth System*, 2nd ed. (Pearson, 2004), p. 50

Satellite Measurements

Radiative forcing by clouds

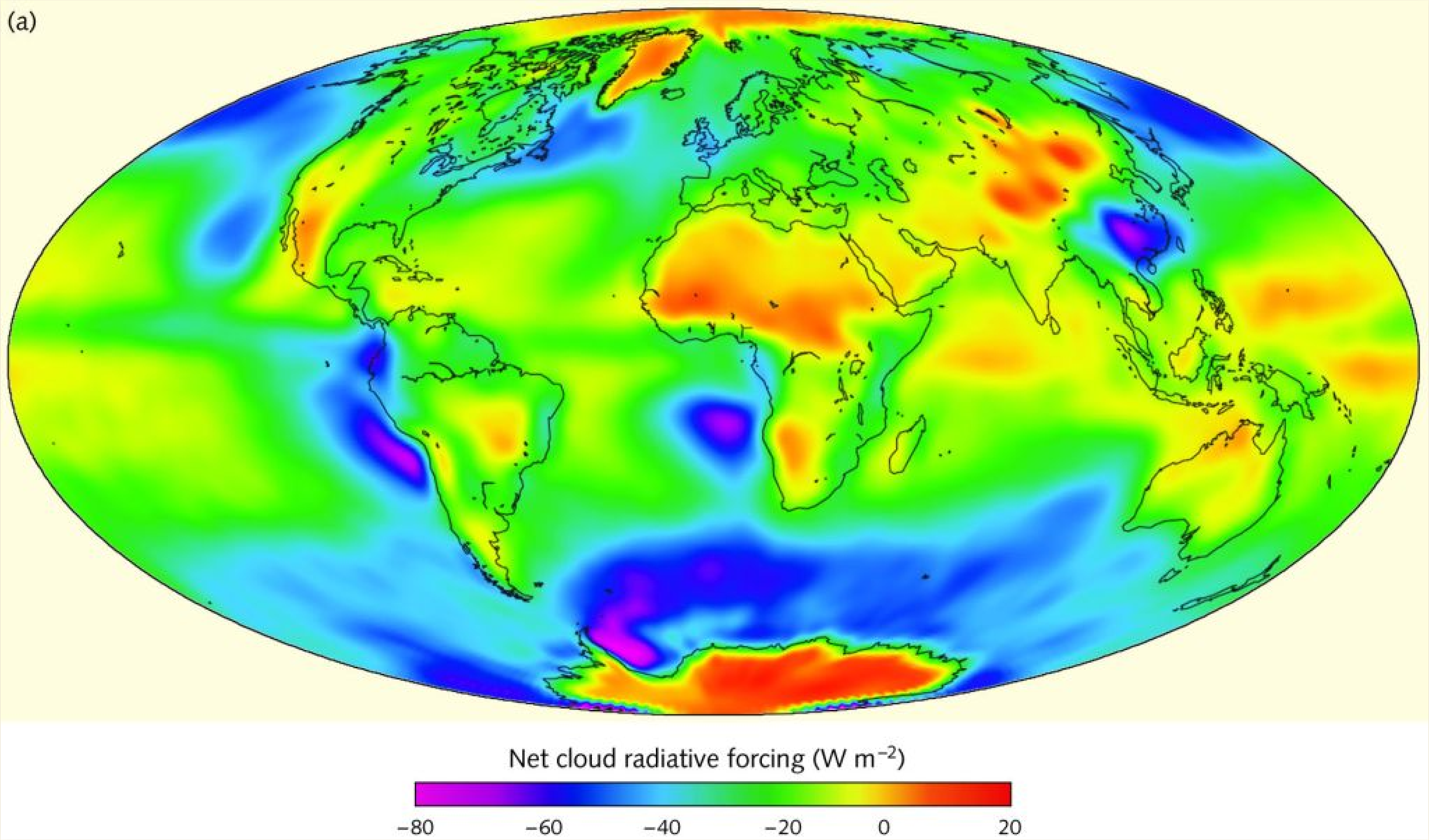
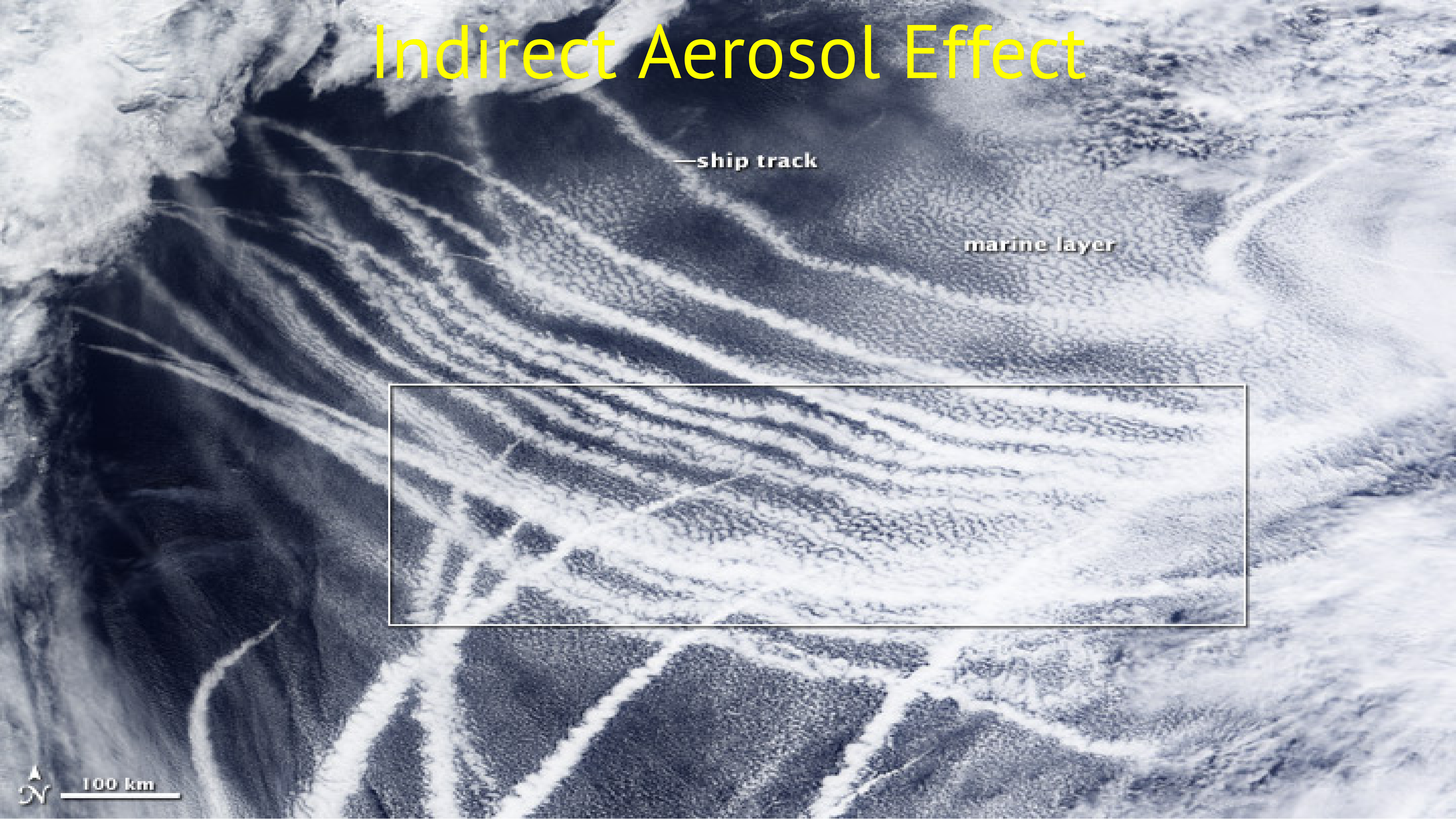


Image credit: NASA CERES/Terra experiment, Net Cloud Radiative Forcing, Nov. 2007 https://ceres.larc.nasa.gov/documents/press_releases/images/netcrf_small.png

(negative = cooling, positive = warming)

Indirect Aerosol Effect



Indirect Aerosol Effect

- Aerosol particles $\longrightarrow$ more, smaller droplets
- Smaller droplets $\longrightarrow$ greater albedo, longer lifetime
- More droplets $\longrightarrow$ greater albedo, more absorption

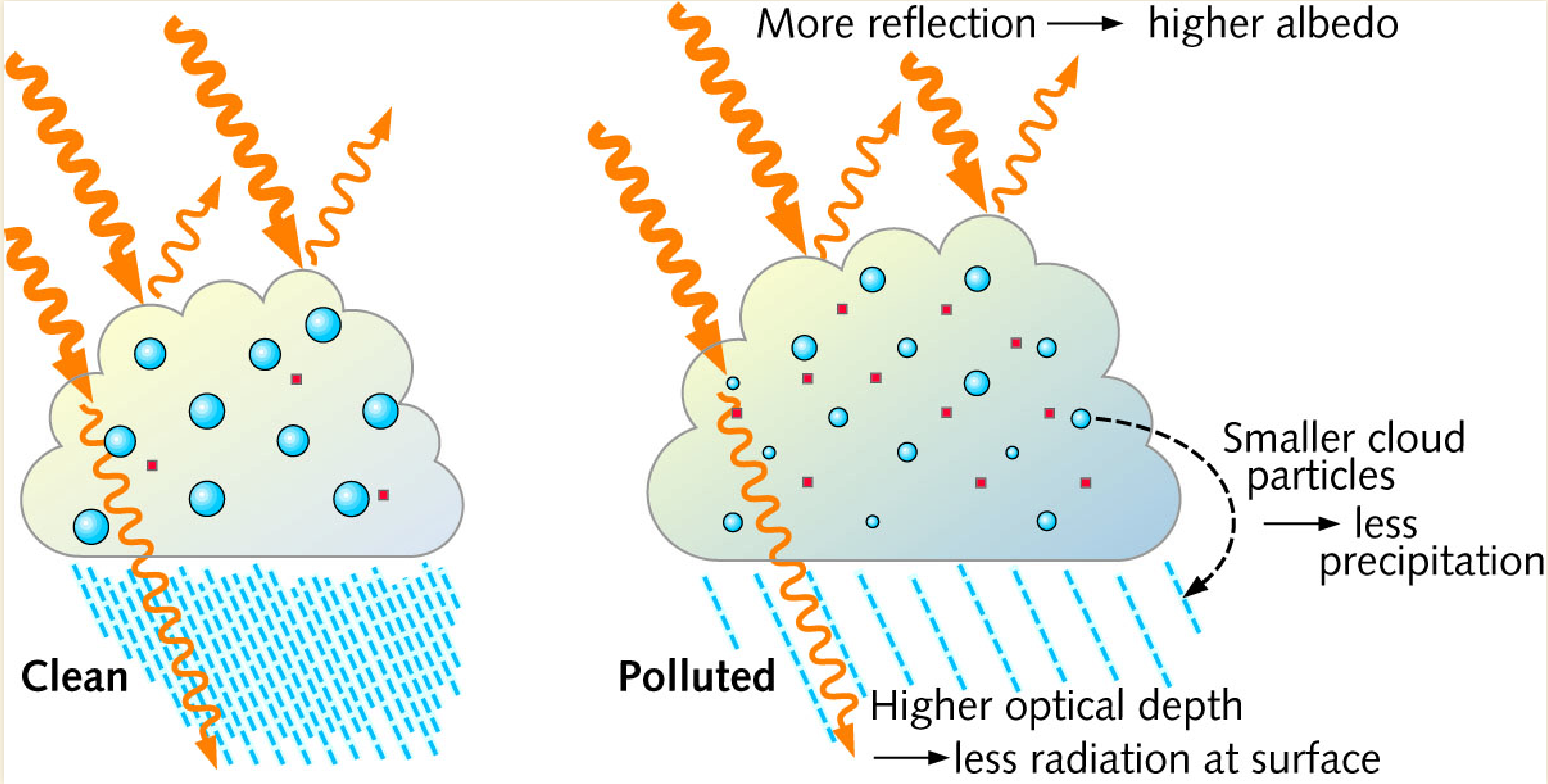


Image credit: J. Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge, 2009), p. 61

Indirect Aerosol Effect

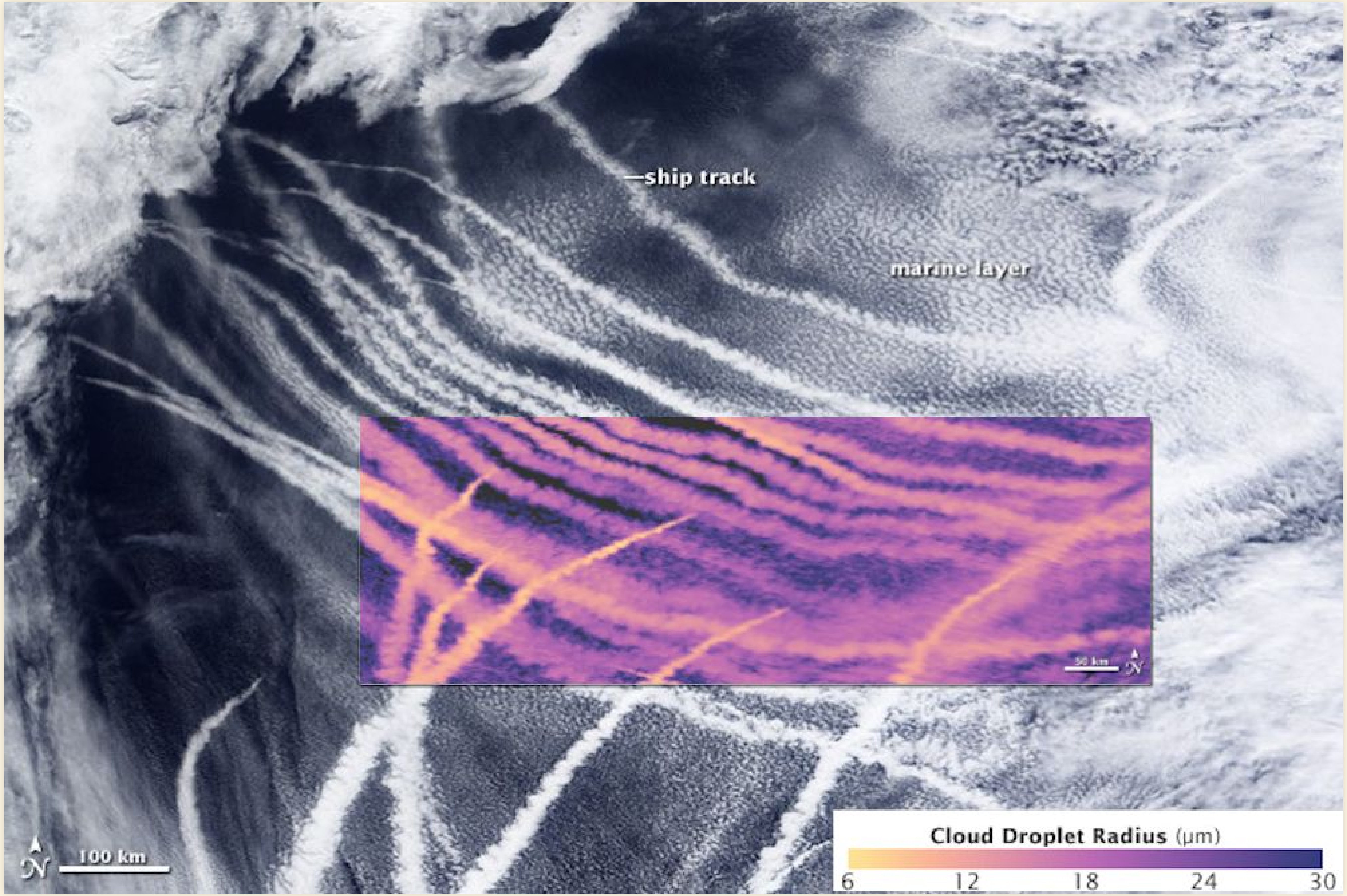


Image credit: NASA Earth Observatory, Ship Tracks South of Alaska, Mar. 4 2009. https://earthobservatory.nasa.gov/images/37455/ship-tracks-south-of-alaska

Summary of Feedbacks

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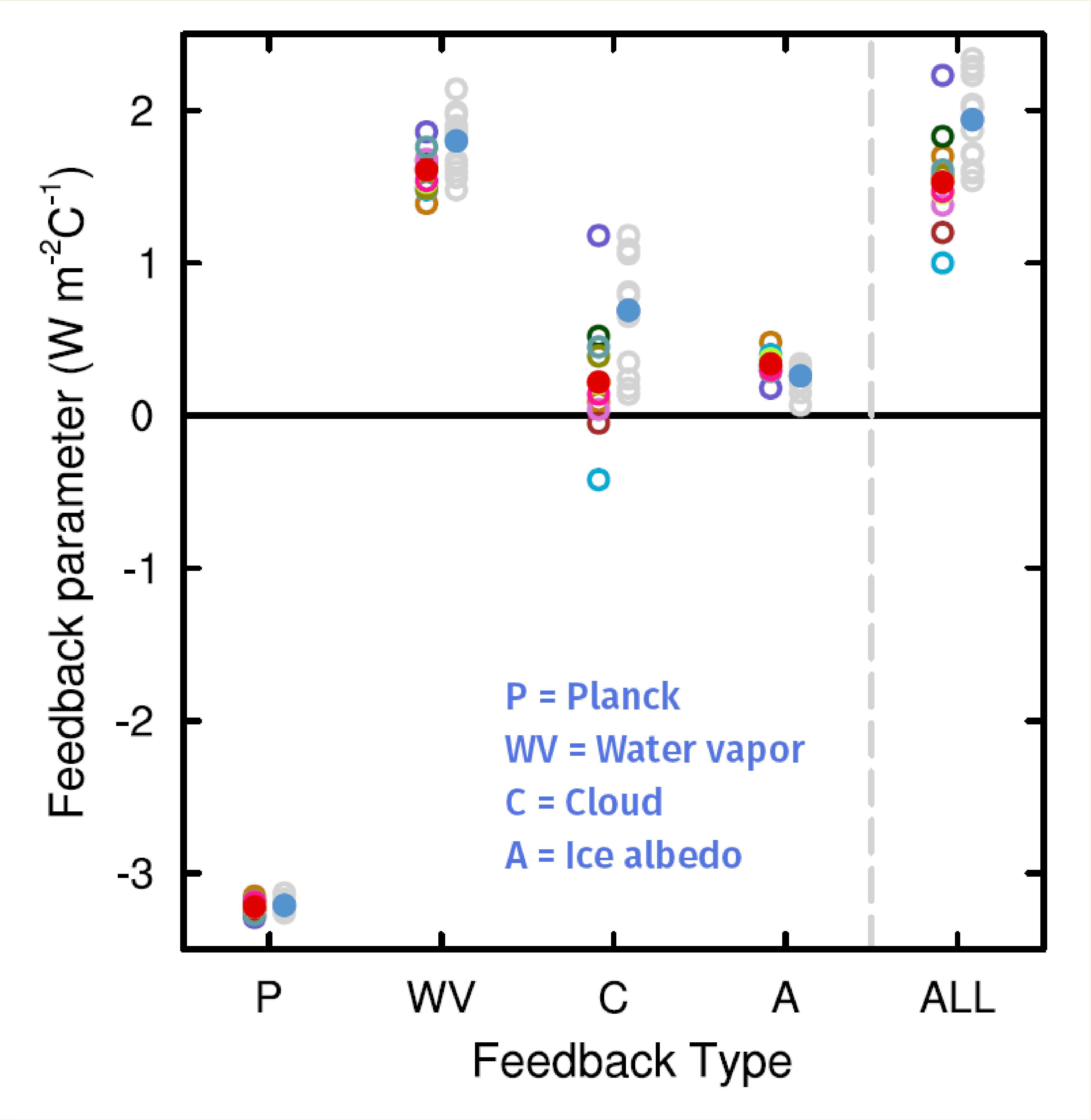


Image credit: IPCC 5th Assessment Report, *Climate Change 2013: The Scientific Basis*, Ch. 9, Fig. 9.43. https://www.ipcc.ch/report/ar5/wg1/evaluation-of-climate-models/fig9-43-2/

Stefan-Boltzmann Feedback

- The biggest feedback in the climate system is the Stefan-Boltzmann feedback.
- Stefan-Boltzmann equation: $I = \varepsilon\sigma T^4$
  - $Q = Q_{\text{in}} - Q_{\text{out}}$
  - Higher temperature $\rightarrow$ more heat out to space
    - Q_{out} gets larger, so $\Delta Q < 0$
  - $\Delta T > 0 \rightarrow \Delta Q < 0$
  - $f = \dfrac{\Delta Q}{\Delta T} < 0$: negative feedback
- Creates stable climate

Stability of the Climate

- Most feedbacks we’ve discussed are positive:
  - Ice-albedo
  - Water vapor
  - Clouds (mostly)
- Why don’t these positive feedbacks make the climate unstable?
  - (e.g., runaway greenhouse)
  - They are smaller than the negative Stefan-Boltzmann feedback
    - so the total feedback remains negative.
  - Positive feedbacks amplify warming:
    - More than we’d get with just Stefan-Boltzmann feedback,
    - But they are too small to destabilize the planet.
- Some scientists worry about a possible “tipping point”:
  - Is there a temperature threshold where positive feedbacks become greater than Stefan-Boltzmann?
    - This would destabilize the climate.
    - Venus-style runaway greenhouse effect seems impossible.
    - But some uncontrolled warming is possible.

Feedback Mathematics

Stefan-Boltzmann Feedback

Bare rock:

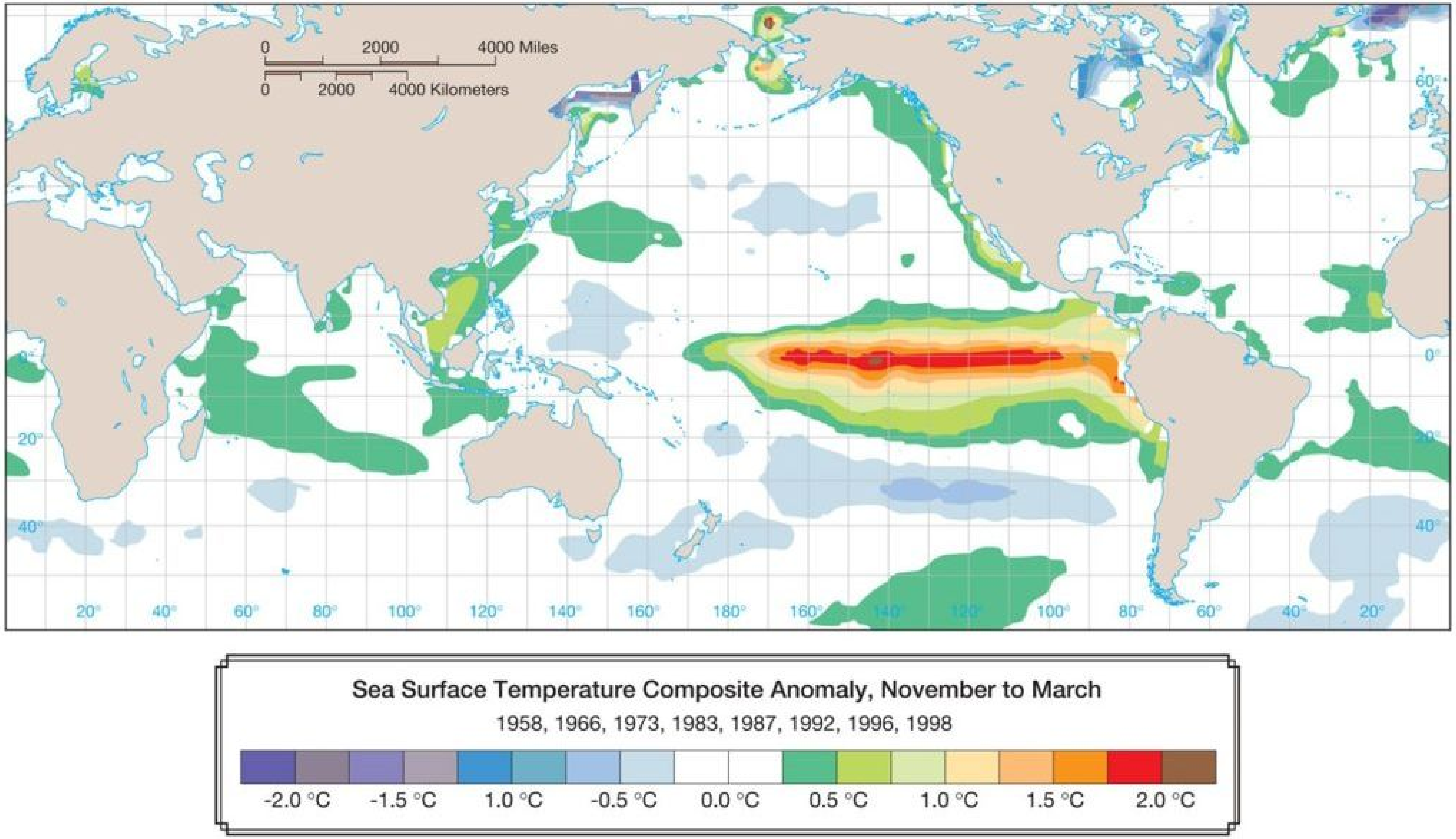
- $I_{\text{out}} = \epsilon\sigma T^4$
- $f_{\text{SB}} = -3.2\,\text{Wm}^{-2}\text{K}^{-1}$
- Forcing: $Q_{\text{forcing}} = I_{\text{in}} - I_{\text{out}} = +1\,\text{Wm}^{-2}$
- $\Delta T = -Q_{\text{forcing}}/f$

$$\Delta T = \frac{-1\,\text{Wm}^{-2}}{-3.2\,\text{Wm}^{-2}\text{K}^{-1}} = +0.32\,\text{K}$$

Positive & Negative Feedback

- Total feedback: $f = f_0 + f_1 + f_2 + \cdots$
- $f_0 = f_{\mathrm{SB}}$: Stefan-Boltzmann
- Other feedbacks $f_1, f_2, \cdots$:
  - Positive ($f_1, f_2, \ldots > 0$): amplifies temperature change
    - Warmings $\rightarrow$ hotter
    - Coolings $\rightarrow$ colder
  - Negative ($f_1, f_2, \ldots < 0$): diminishes temperature change
    - Warmings $\rightarrow$ milder
    - Coolings $\rightarrow$ milder

El Niño/Southern Oscillation



Normal Conditions

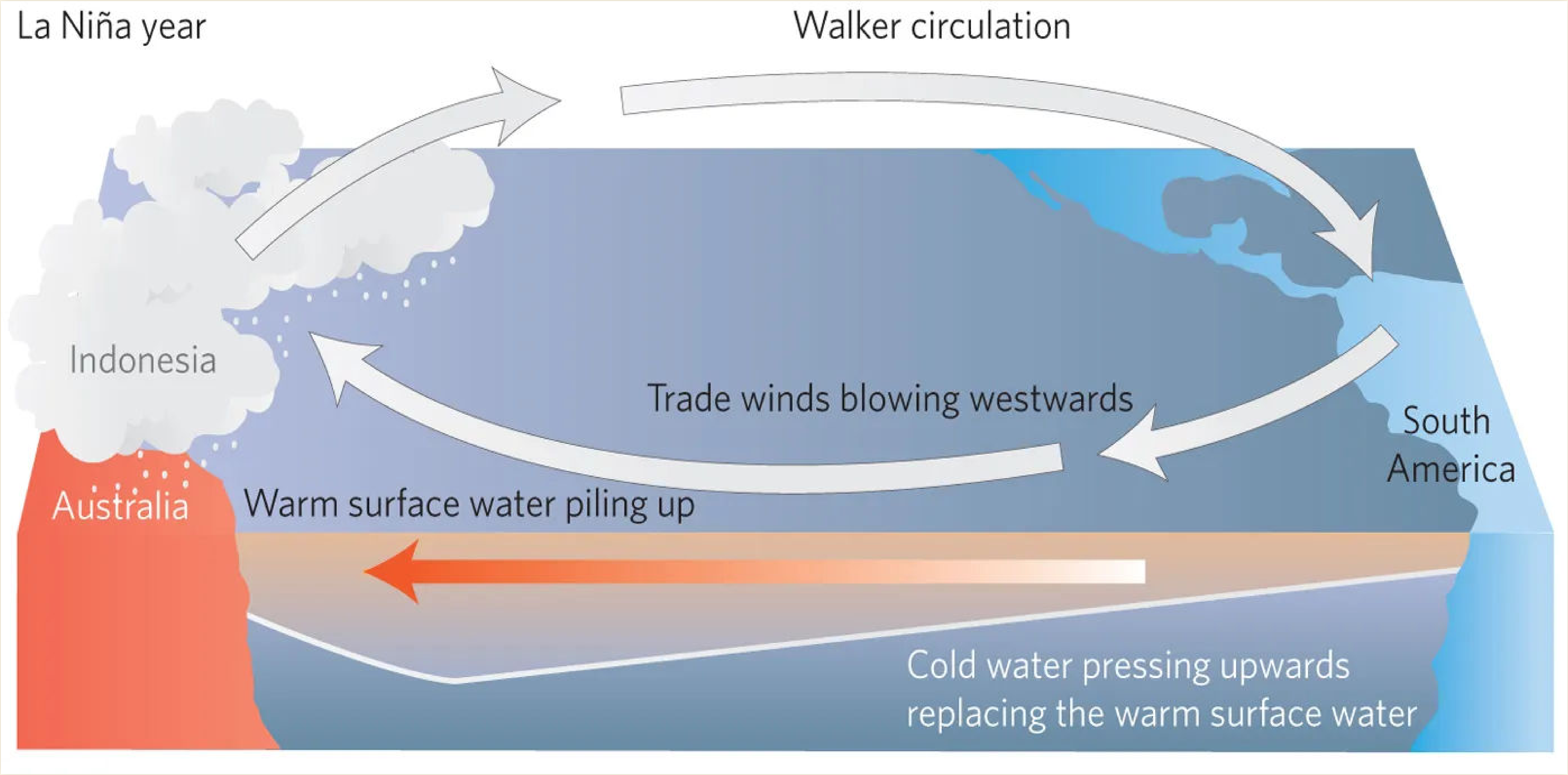


Image credit: O. Heffernan, Nature Climate Change **4**, 167 (2014). doi 10.1038/nclimate2149

El Niño

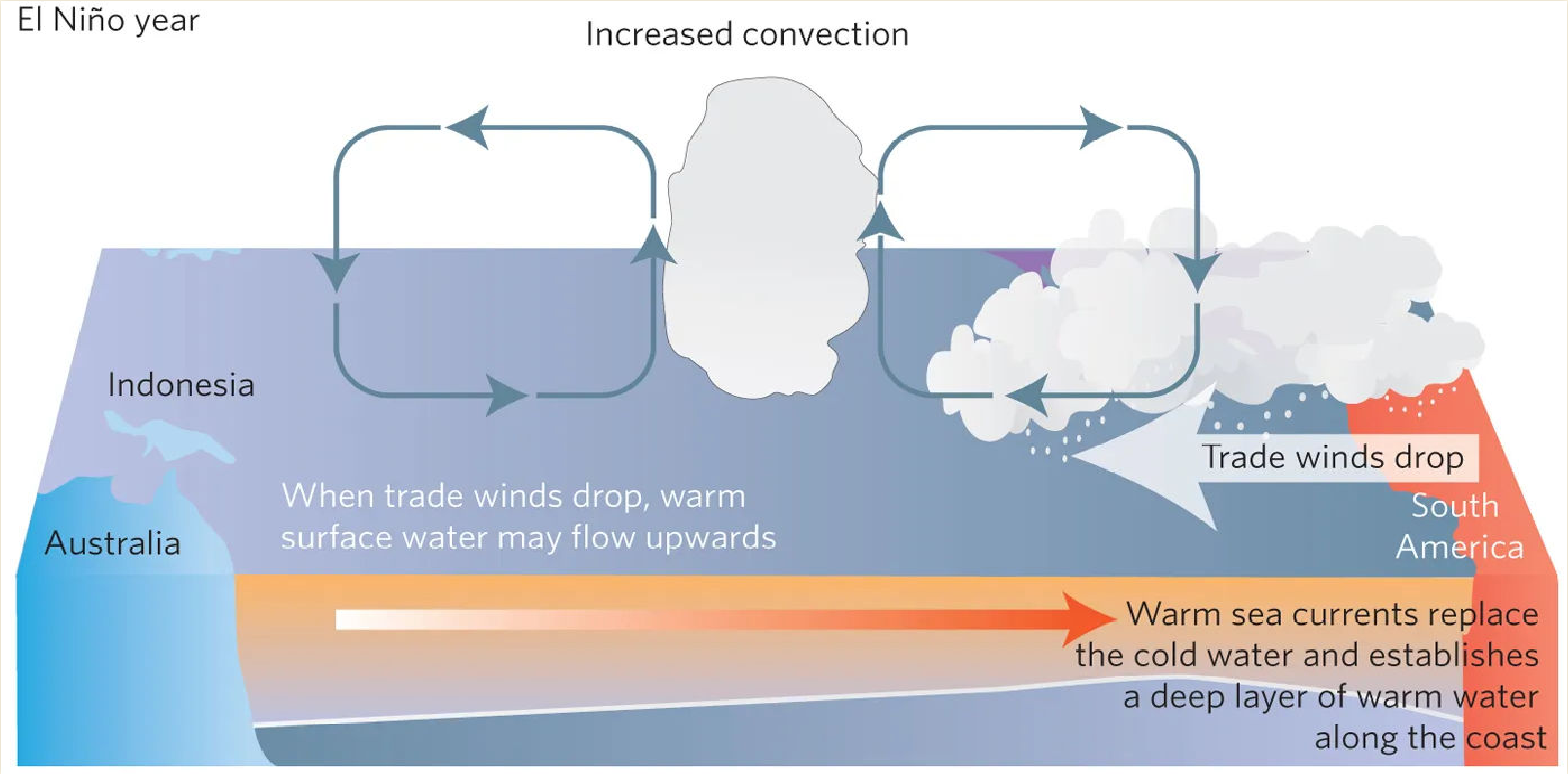


Image credit: O. Heffernan, Nature Climate Change **4**, 167 (2014). doi 10.1038/nclimate2149

Schematic of ENSO Wind & Temperature

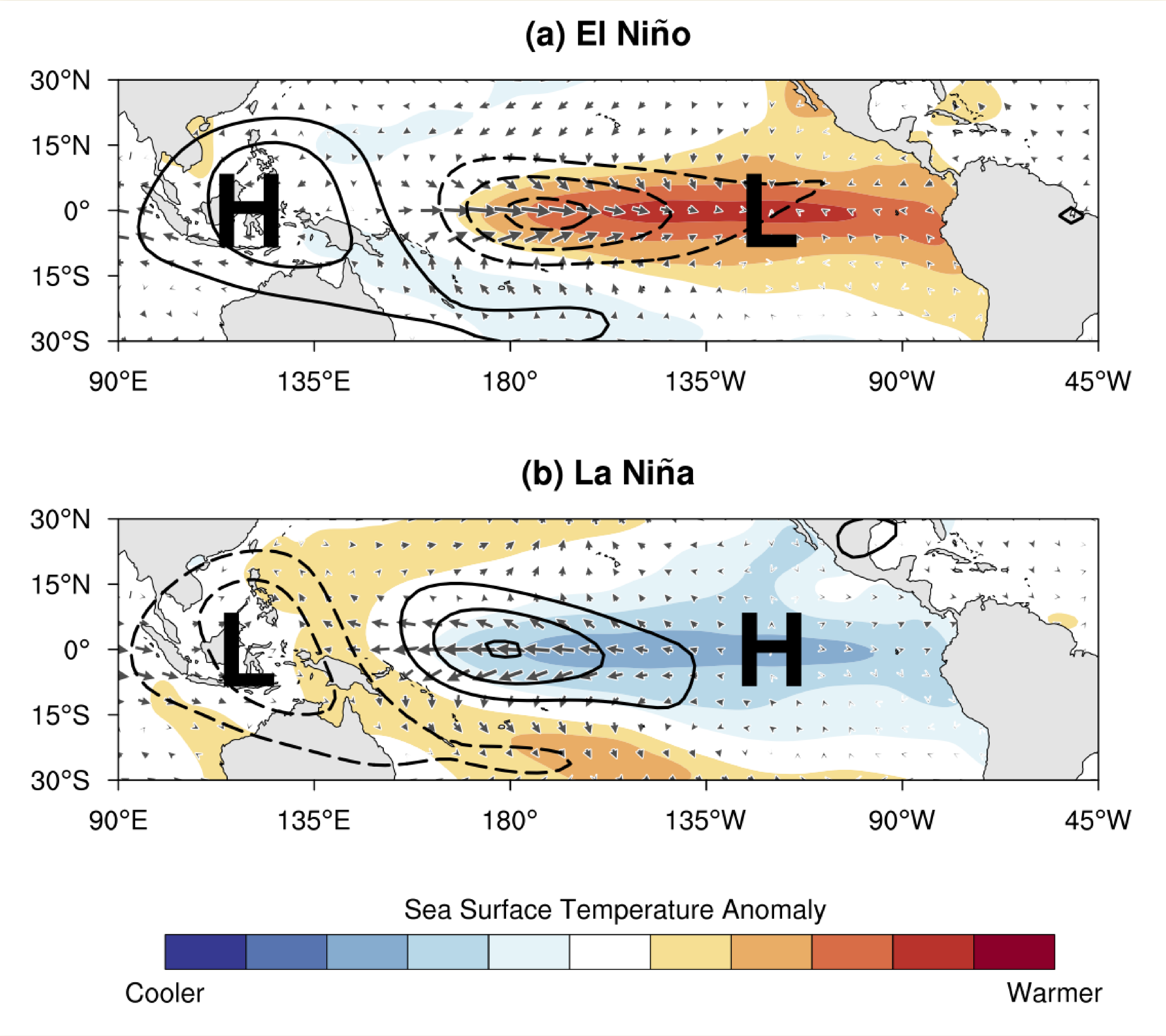
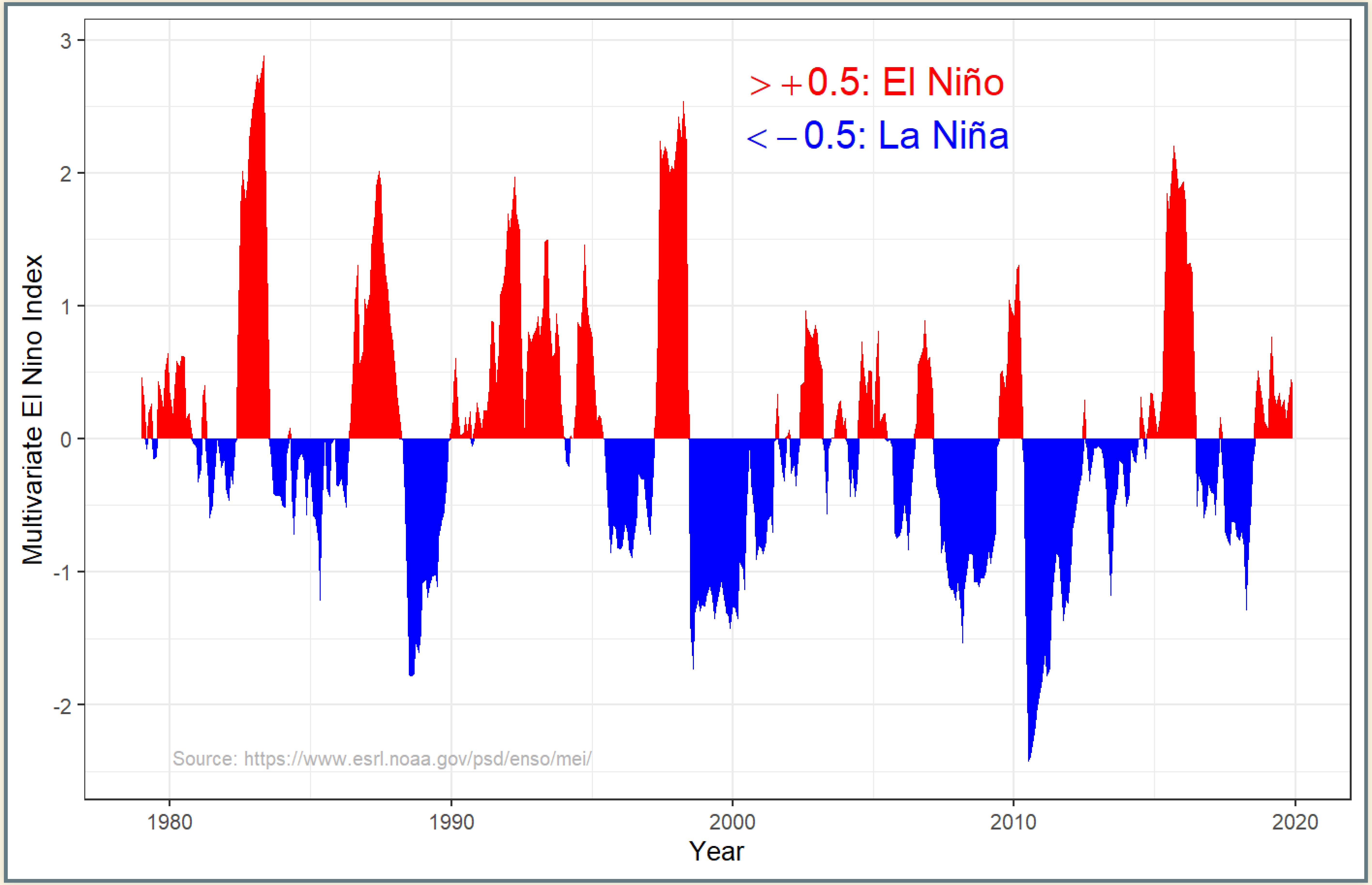


Image credit: National Oceanic & Atmospheric Administration, Multivariate ENSO Index Version 2 https://www.esrl.noaa.gov/psd/enso/mei/

Multivariate El-Niño Index (MEI)



Climate Connection

- El Niño phase:
  - Hotter sea-surface
  - More evaporation
  - Bigger greenhouse effect
  - Higher global air temperatures
- La Niña phase:
  - Cooler sea-surface
  - Less water vapor
  - Smaller greenhouse effect
  - Cooler global air temperatures

Biosphere Feedbacks

Hydrological Cycle

- Transpiration in plants:
  - Roots take water from ground
  - Leaves emit water vapor
    - Evaporation cools the air
    - Can be an important source of water vapor

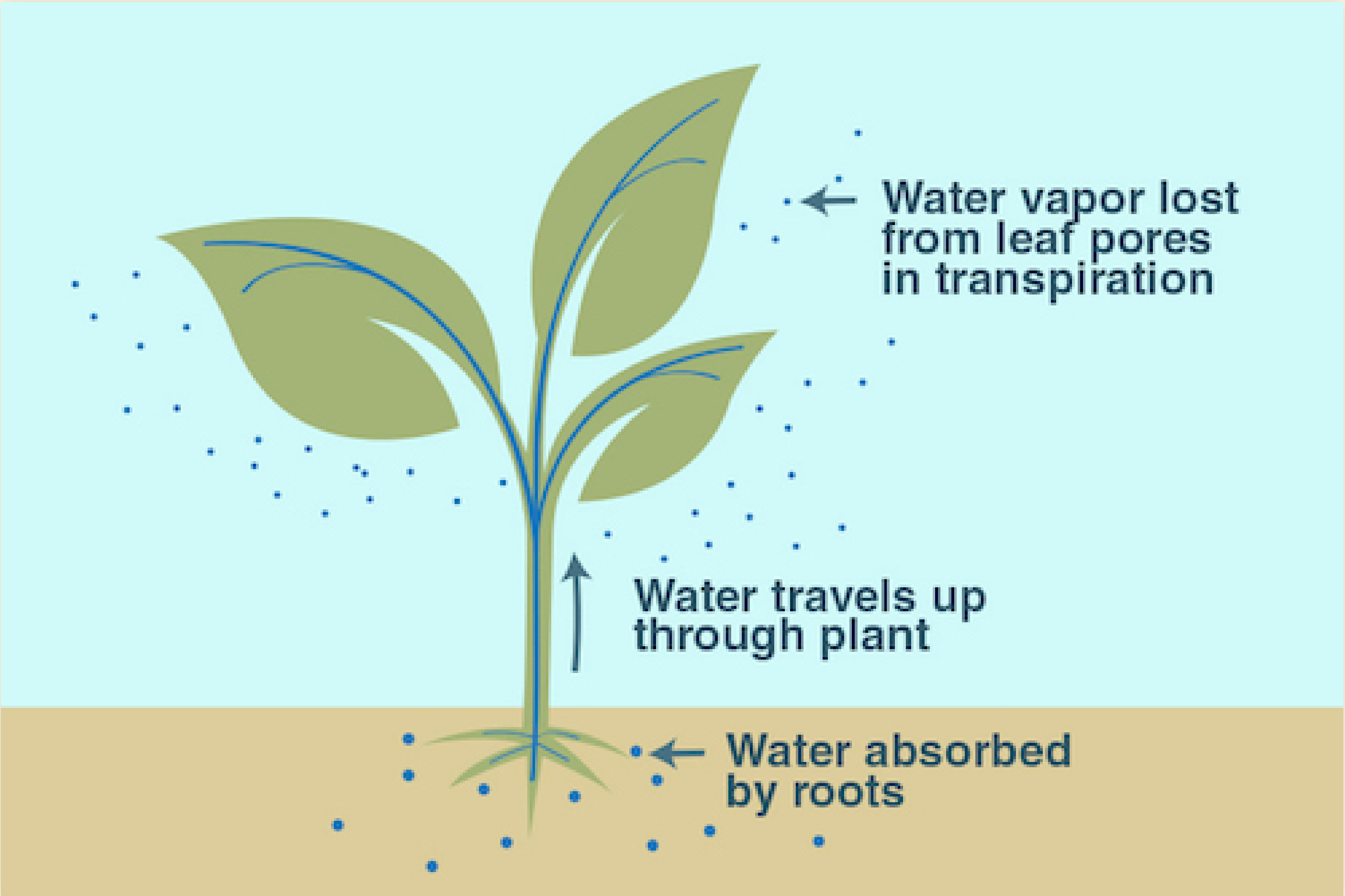


Image credit: NASA/JPL-Caltech https://climatekids.nasa.gov/heat-islands/

Transpiration and CO_2

- Transpiration occurs through "stomata" in leaves
- Tradeoff: stomata
  - Allow plant to get CO_2
  - Cause plant to lose water
- More CO_2 in atmosphere:
  - Fewer stomata
  - Less transpiration

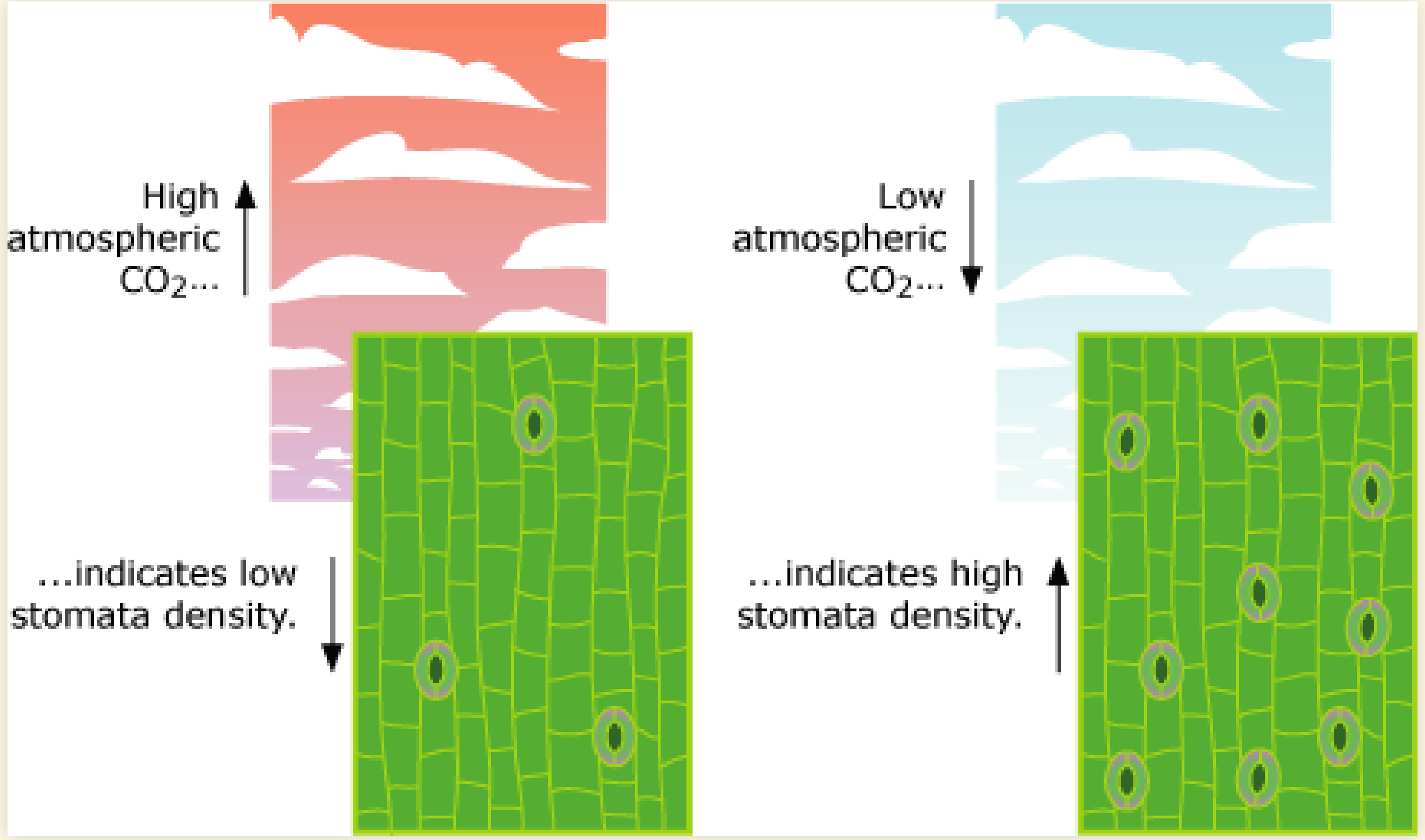


Image credit:
- Photo of stomata on duckweed: Micrographia http://www.micrographia.com/specbiol/plan/planaq/plaq0100/lemna-01.htm.
- Diagram of response to CO_2: University of California Museum of Paleontology's Understanding Evolution http://evolution.berkeley.edu.

Forests vs. Grasslands

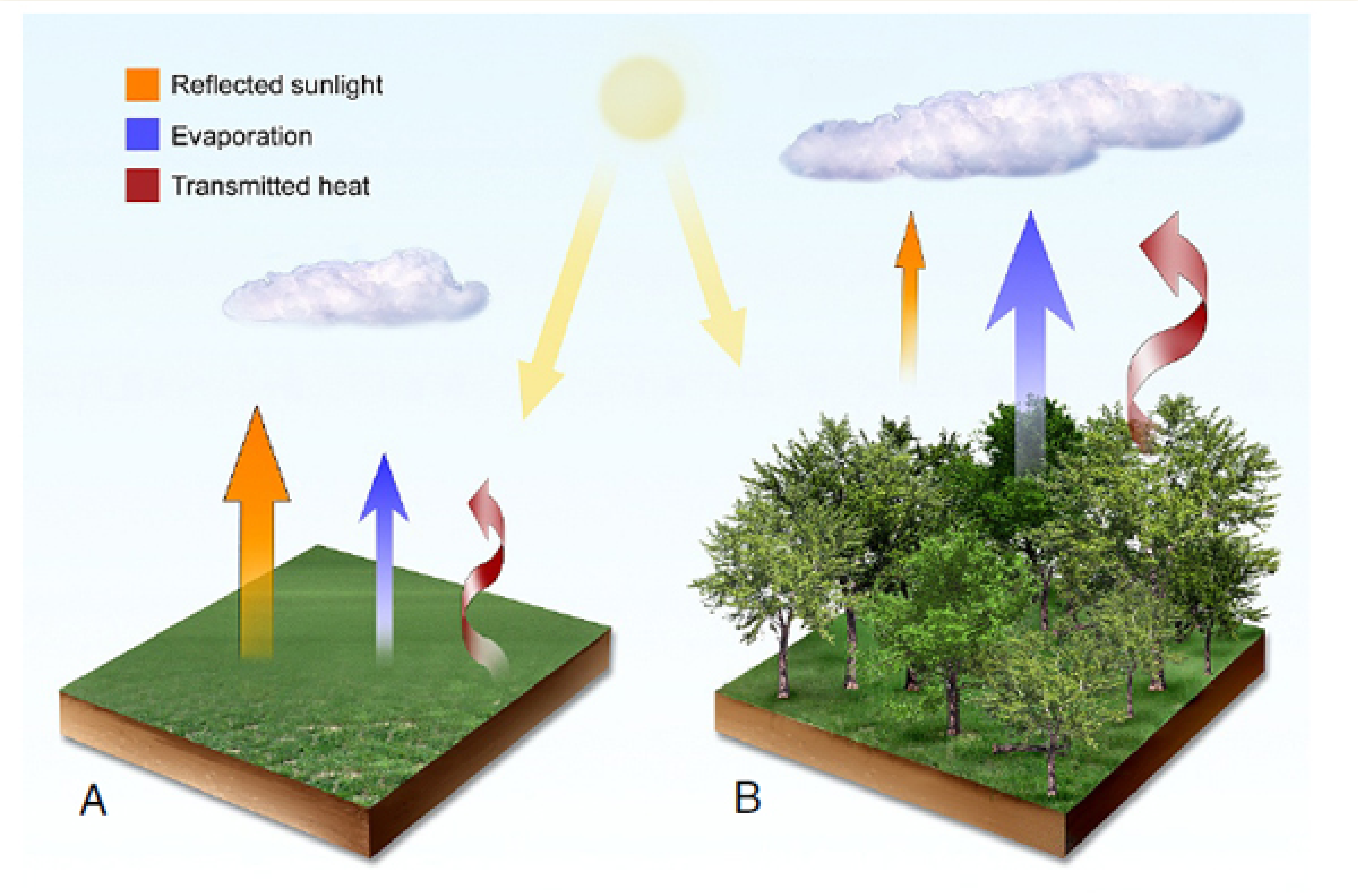


Image credit: R.B. Jackson *et al.*, Environ. Res. Lett. **3**, 044006 (2008). doi: 10.1088/1748-9326/3/4/044006

Carbon Cycle Feedbacks

- Dead organic matter in ground (leaves, roots, etc.) stores carbon
- Warming temperatures accelerate decomposition
  - Bacterial/fungal metabolism
- Huge amounts of dead organic matter in arctic tundra & permafrost
  - Concerns about accelerated greenhouse gas emissions as ground thaws & warms

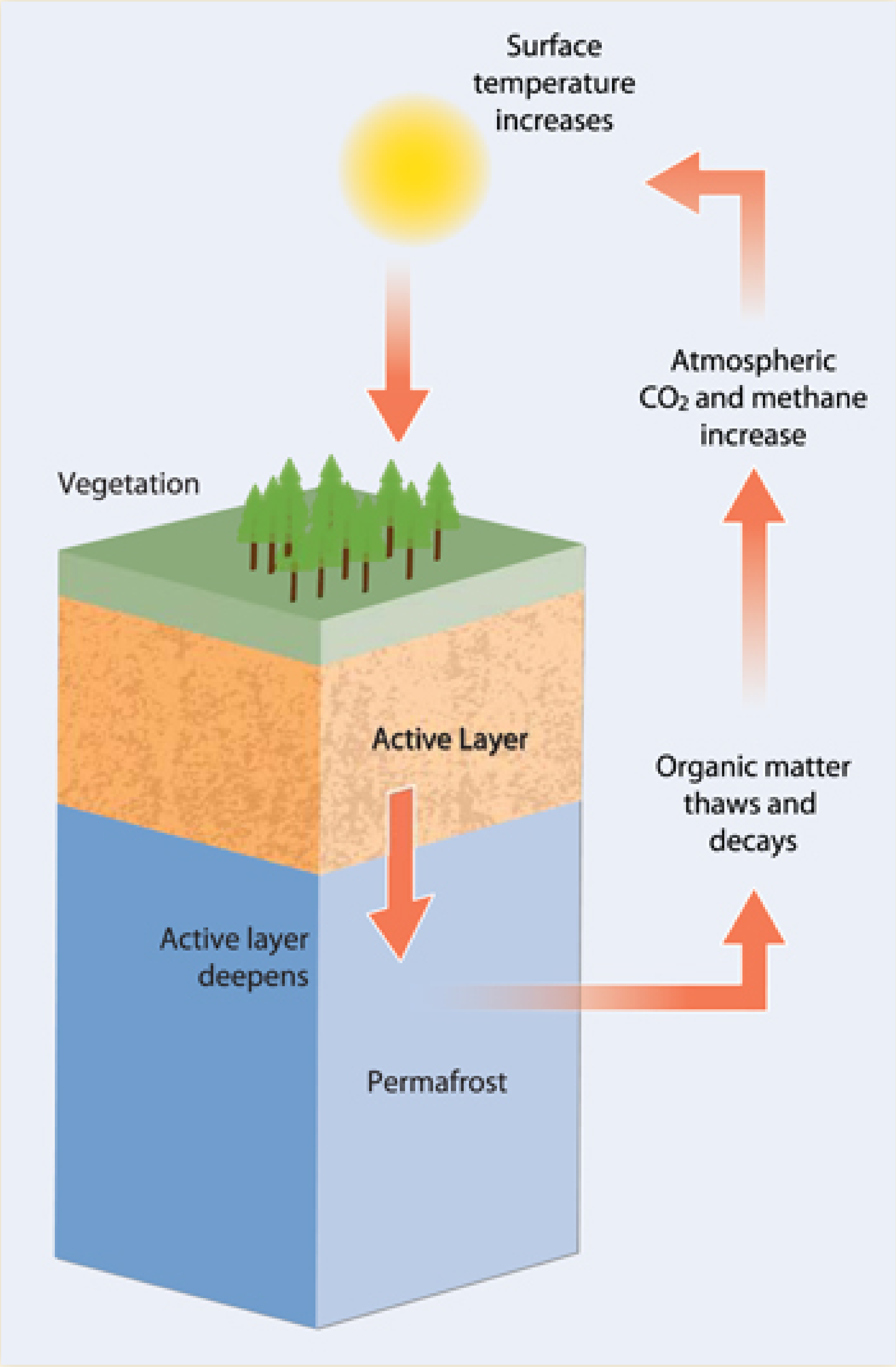


Image credit: K. Schaefer *et al.*, Environ. Res. Lett. **9**, 085003 (2014). doi: 10.1088/1748-9326/9/8/085003